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PRELIMINARY PROJECTIONS OF OIL SPILL MOVEMENT FOR THREE POTENTIAL DEEPWATER PORT SITES IN THE GULF OF MEXICO

I. M. Lissauer

J. P. Welsh

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ERRATA

Page 14, paragraph 3.2, third line should read:

"east-southeast" vice "south-southwest"

Page 28, paragraph 4.2, second line should read:

"in Figures 9, 10, 15 and 16....."

Page 28, paragraph 4.3, first line should read:

"Figures 11 and 12....."

19

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16. Abstract

Projections of the movement of oil slicks and their impact location along the shorelines of Texas, Louisiana, Mississippi, Alabama and Florida were determined from three potential deepwater port sites. Average monthly wind speeds and directions and average monthly current patterns were used for predicting the oil slick movement. Seasonal patterns of oil slick drift and probable areas of impact along the shoreline were indicated.

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1.0 SUMMARY

1.1 Purpose and Scope

There are many possible deepwater port sites along the northern Gulf Coast of the United States. The general areas of three potential deepwater port sites are located off the coasts of Texas (Galveston area), Louisiana and Mississippi (Figure 1). To understand the economic and ecologic implications of a spill from any of these potential sites, predictions of the movement of oil slicks and their impact location along the shoreline must be determined.

This report is designed to investigate the paths of movement of oil slicks, from the three potential sites, using average monthly wind speeds and directions and average monthly and seasonal current patterns. The technique used to predict oil slick movement does not indicate where an actual spill might move. Rather, it indicates broad areas of the coastline which are most susceptible to environmental damage should a spill occur. For greater precision in determining where actual oil spills would drift, a computer model for the area should be developed (either a new model or an adapted model) and used to predict oil slick movements.

1.2 Conclusions

a. A large oil spill occurring at any of the potential Deepwater Port sites could cause severe environmental damage along the coastline.

b. Spills at DWP 1 will impact the shoreline approximately 55-60% of the time.

c. Spills at DWP 2 will impact the shoreline approximately 40-50% of the time.

d. Spills at DWP 3 will impact the shoreline approximately 65% of the time during the winter season and 35-65% of the time during the summer.

e. Spills at DWP 1 will take a minimum of 27-34 hours to impact the shoreline.

f. Spills at DWP 2 will take a minimum of 19-33 hours to impact the shoreline.

g. Spills at DWP 3 will take a minimum of 24-136 hours to reach the shoreline.

h. Further research is needed in order to quantify the effect of the wind on the current regime.

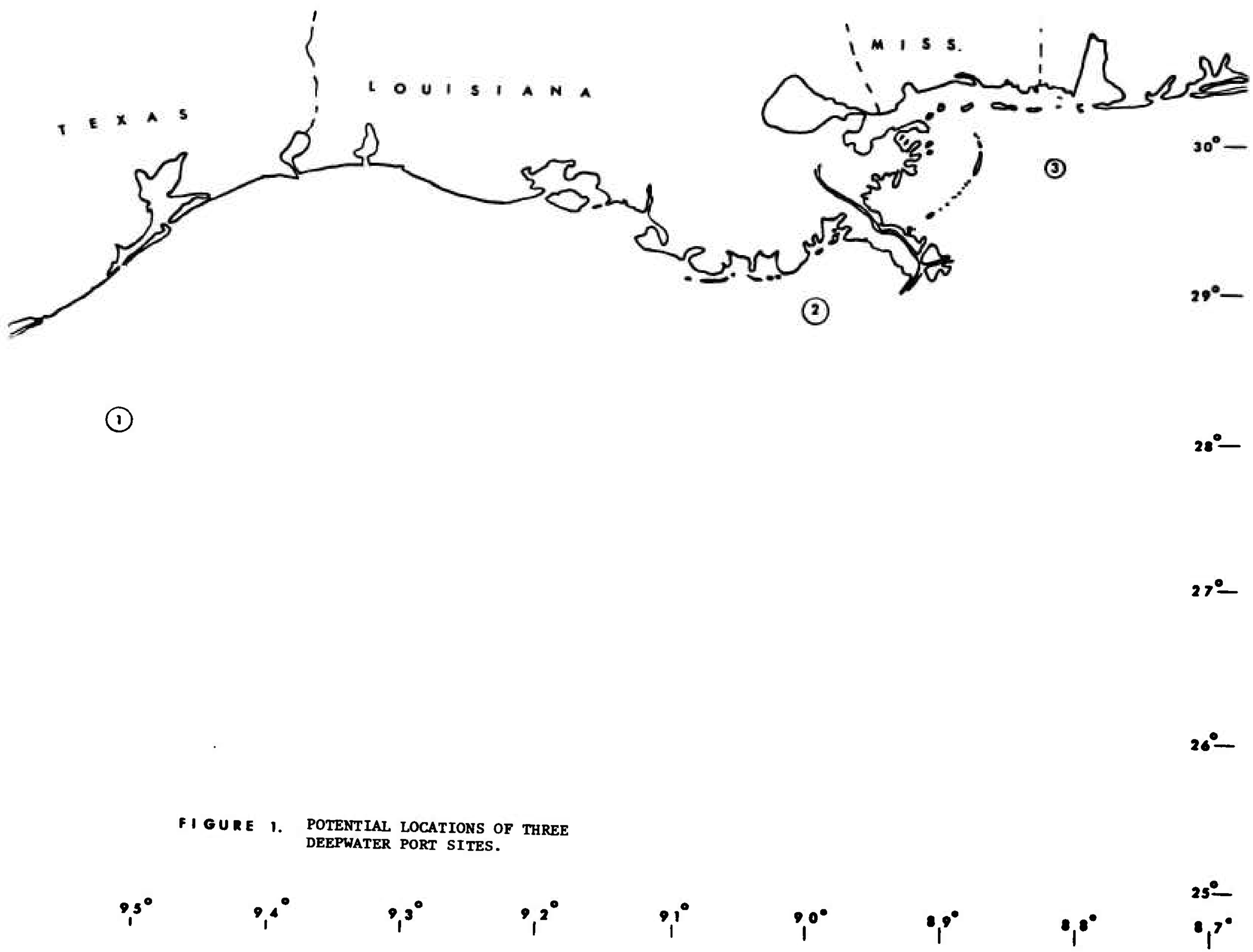


FIGURE 1. POTENTIAL LOCATIONS OF THREE DEEPWATER PORT SITES.

2.0 ENVIRONMENTAL PARAMETERS

2.1 Wind Data

Surface winds play an important role in the transport of oil on the water. A wind continuing for some time will produce a current the velocity of which depends on the velocity of the wind. The wind drift of an oil slick can be described by a wind factor: oil slick drift rate as a percentage of wind speed. Empirical investigations indicate that the wind drift factor is in the range of 3.0 to 4.5 percent. Actual observations of oil slick movement at sea include the Torrey Canyon slick, 3.4%, and the Gerd Maersk slick, 4.3% (Tomczak 1964). Smith (1974) conducted field experiments off the Virginia coastline to determine the leeway of oil slicks. Based on these determinations a wind factor of 3.64% ± 0.51% was calculated. Schwartzberg (1970) conducted laboratory drift rate experiments. He obtained a value of 3.66% ± 0.17% from his experiments in a small-scale test basin. Lissauer (1974) showed that a value of 3.5% could be used to successfully predict the movement of oil spills in New York Harbor.

Although 3.5% of the wind speed appears to be a usable wind drift factor for predicting oil spill motion, this may not be the case when wind speeds are in excess of 20 knots. Above 20 knots wind speed, wave-induced drift appears to be a significant factor in determining the drift of slicks. The relationship between wind drift and wave drift is quite complex and has not been quantified, therefore it has been ignored in this study.

Disagreement persists over the magnitude of deviation from wind direction to be expected for oil slick movement. Ekman's theory postulates that the wind drift deflects to the right, finally attaining an angle of 45° to the right of the wind in the northern hemisphere. However, in shallow water the deflection is at a minimum because frictional forces balance the Coriolis force. Oil slick drift observed by Smith (1974) was directly downwind as was the drift of the Torrey Canyon slick. Another factor which may contribute to the downwind water flow is the previously mentioned wave transport. This transport acts directly downwind all through the mixed layer. As wind speed increases and wave height increases this transport becomes more significant and may explain the tendency for oil slicks to move downwind.

Historical wind data for the Gulf of Mexico is available from the Summary of Synoptic Meteorological Observations - North American Coastal Marine Areas - Volume 6. Extracted from Volume 6 is Table 1 which shows the average speed of the wind system for each deep water port for eight different wind directions. These statistics are given for both summer and winter periods. These data are used in Section 3.0 to determine the relationship between the wind and the current system at each deep water port site.

2.2 Current Data

Most of the surface current data was obtained from Marcus (1973). The basic sources for this study were H. O. Pub. No. 700 Series Section I, Tides and Currents for the Gulf of Mexico, and Navy analysis of maximum

Table 1

Average Wind Speeds ($\overline{W}$) for Summer (Jul-Aug-Sep) and Winter (Jan-Feb-Mar) for Eight Directions for Each Deepwater Port

	Summer		Winter	
Direction	No. of Observations	$\overline{W}$	No. of Observations	$\overline{W}$
		DWP 1		
N	847	9.6	1804	15.7
NE	1527	10.6	1612	14.0
E	2576	10.3	1974	12.6
SE	3092	10.4	2444	12.1
S	2432	9.9	1500	11.5
SW	996	8.8	423	10.5
W	729	9.0	562	14.1
NW	429	8.9	1040	16.5
Calm	590	--	208	--
Total	13218		11567	
		DWP 2		
N	1446	9.3	2982	15.5
NE	2756	10.5	3035	14.5
E	5040	10.5	3356	13.1
SE	3895	10.4	3566	12.9
S	2914	10.2	2279	12.8
SW	1675	9.5	798	11.8
W	1609	9.2	1138	15.9
NW	1073	9.2	2034	16.9
Calm	1307	--	285	--
Total	21715		19473	
		DWP 3		
N	1164	8.5	2235	14.8
NE	2316	9.8	2110	13.6
E	3961	10.7	2561	13.1
SE	2718	10.0	2613	13.1
S	2037	9.6	1538	13.0
SW	1539	10.0	726	12.5
W	1569	9.5	1150	16.0
NW	986	9.1	1679	16.9
Calm	997	--	185	--
Total	17287		14797	

current speeds by 1° quadrangles for the Gulf of Mexico. Other sources, some summaries and some specific observations were also included. The study area was divided into four regions based on statistics given in Marcus (1973). Identification and location of these regions is shown in Figure 2. Some statistics for each of these regions for summer and winter seasons are presented in Table 2. This table gives the number of observations for each region, the average speed of the currents in the regions, the prevailing direction of the currents, the direction of the maximum current speeds, and the mean speeds of currents in the direction of maximum currents.

Most of what is known of the surface currents in the mesoscale is given in Table 3. The data are presented for summer and winter seasons for each deep water port. Small-scale variations in both time and space are not accounted for in this table. However, this table can be used to determine probabilities of ocean current parameters, and are usable for determining the probable movement of an oil spill.

Other current data available are shown in Figures 3 and 4 and Table 4. Maximum observed current speeds without regard to direction are shown for regions A, B, C and D of Figures 3 and 4. They are the maximum values ever reported by ship-observation over the years and are presented by 1° quadrangles of latitude and longitude. Since these statistics are based on ship drift readings they are somewhat biased due to the leeway of the vessel (drag of the wind on the ship's hull creating what might appear to be an ocean current). Generally, the possibility of finding actual current speeds greater than those in the figures is remote. Table 4 from Hann (1974) gives some surface current velocity statistics for areas off Galveston and Sabine.

3.0 DRIFT MECHANISMS

3.1 Currents

Generalized surface current structures in the desired areas are shown in Figures 5 and 6. To obtain these structures it was necessary to assess work previously completed in the Northern Gulf area. This assessment was combined with the current data presented for this area and used to construct the winter and summer generalized surface current patterns.

Generally the current system at Deepwater Port Site 1 has a current pattern which is towards the west and northwest, Figures 5 and 6. Over 40% of the current observations of Table 3 are towards the west and northwest for both summer and winter seasons. The average speed of this predominantly westerly flow is 0.8 knots during the winter season and 0.8 to 0.9 knots during the summer.

Deepwater Port Site 2 conditions are similar to those at Site 1. The predominance of current direction observation is towards the west and northwest. The average speed of the current during both seasons is 0.8 to 0.9 knots.

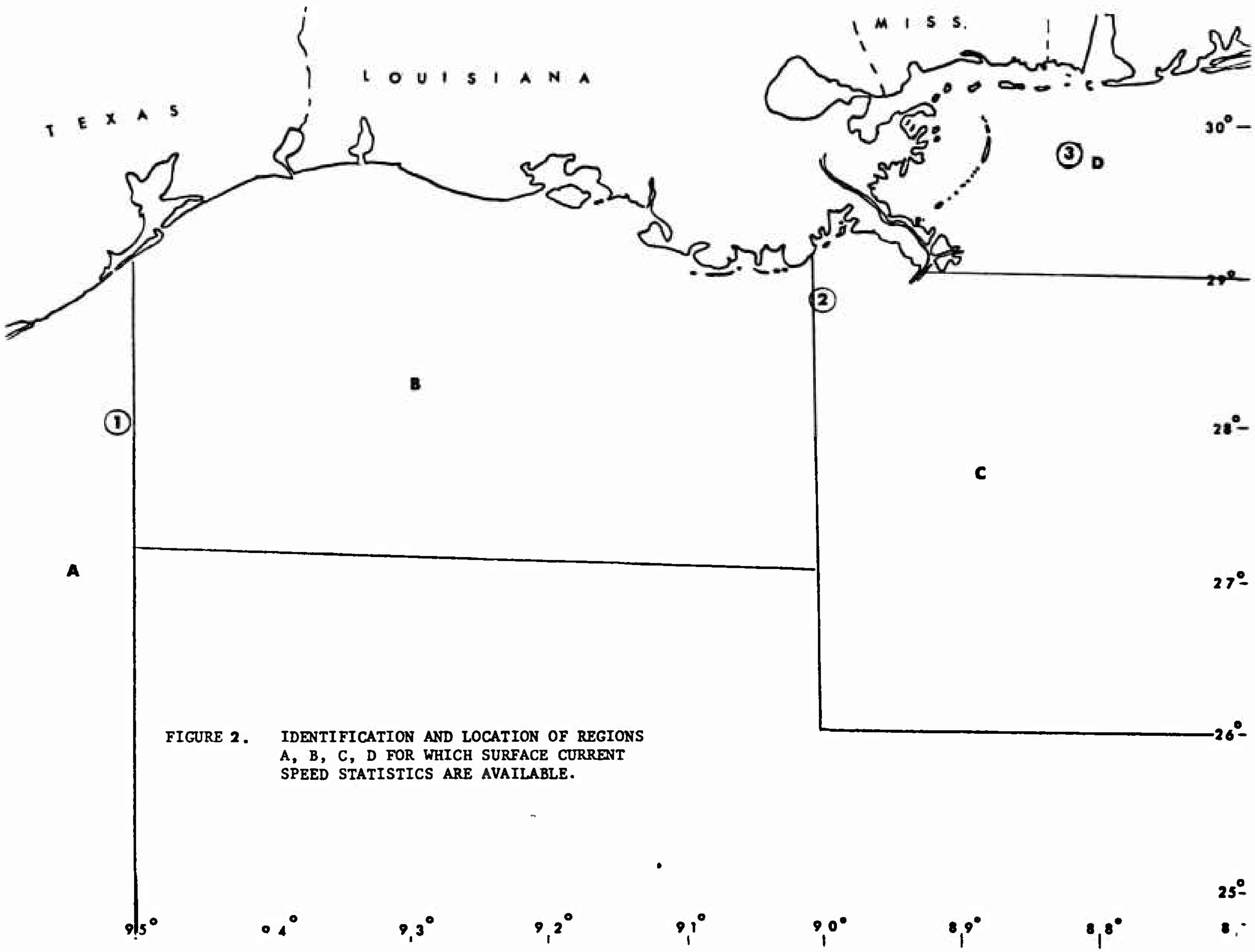


FIGURE 2. IDENTIFICATION AND LOCATION OF REGIONS A, B, C, D FOR WHICH SURFACE CURRENT SPEED STATISTICS ARE AVAILABLE.

Table 2

Surface Current Speed Statistics for Regions A, B, C and D for Winter and Summer

Region	No. of Observations	Speed, V, (KTS) $\overline{V}$	Prevailing Direction	Direction (Deg.) Direction of Max. Current Speed	Mean Speeds of Currents in the Direction of Max. Speeds
			Winter		
A	862	0.70	W	W	0.8
B	10,588	0.75	W	W	0.9
C	11,980	0.81	SE	SE	0.8
D	246	0.74	--	SW	1.0
			Summer		
A	818	0.92	W	W	0.8
B	9,588	0.72	NW	W,NW	0.8
C	10,155	0.90	NW,SE	SE	0.9
D	192	0.79	--	N	0.9

Table 3

Surface Current Average Speed ($\overline{V}$) for Summer (Jul-Aug-Sep) and Winter (Jan-Feb-Mar) Conditions for Eight Directions for Each Deepwater Port

Direction (Towards)	Summer No. of Observations	Summer $\overline{V}$	Winter No. of Observations	Winter $\overline{V}$
DWP 1				
N	1476	0.6	1374	0.6
NE	1279	0.6	1145	0.6
E	984	0.7	801	0.7
SE	787	0.6	801	0.6
S	393	0.5	687	0.6
SW	492	0.6	916	0.7
W	1967	0.8	2633	0.9
NW	1967	0.8	2405	0.8
No Current	492	--	686	--
Total	9837		11448	
DWP 2				
N	2121	0.9	2255	0.8
NE	1928	0.9	2029	0.8
E	2700	1.0	2705	0.9
SE	2700	0.9	3382	0.8
S	964	0.7	902	0.6
SW	964	0.7	902	0.7
W	2507	0.9	4058	0.9
NW	4242	0.8	4960	0.8
No Current	1158	--	1352	--
Total	19284		22546	
DWP 3				
N	21	0.9	32	0.7
NE	19	0.7	27	0.7
E	25	0.6	22	0.6
SE	27	0.7	30	0.5
S	15	0.7	12	0.5
SW	17	0.8	37	1.0
W	26	0.8	34	0.7
NW	34	0.7	39	0.7
No Current	8	--	13	--
Total	192		246	

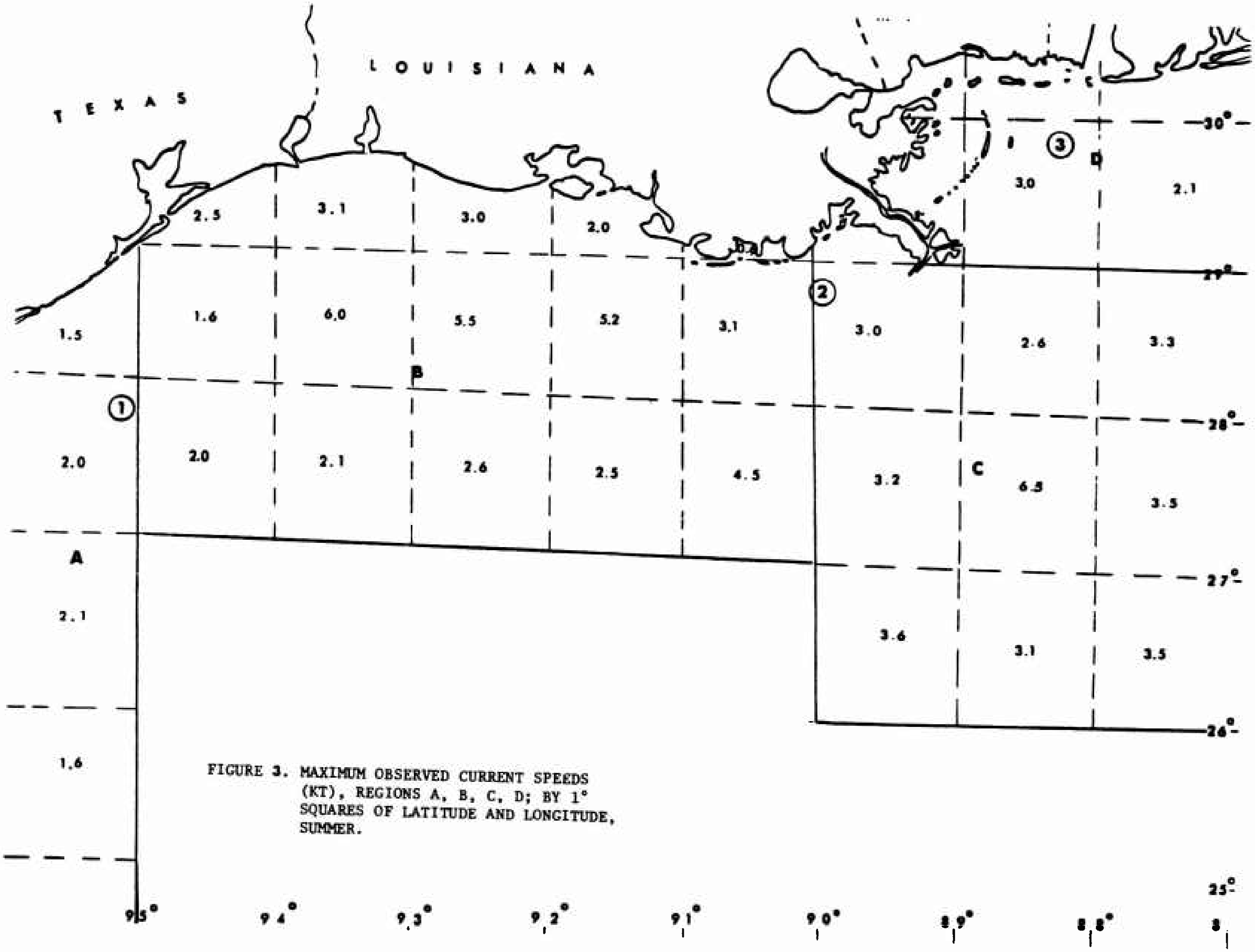


FIGURE 3. MAXIMUM OBSERVED CURRENT SPEEDS (KT), REGIONS A, B, C, D; BY 1° SQUARES OF LATITUDE AND LONGITUDE, SUMMER.

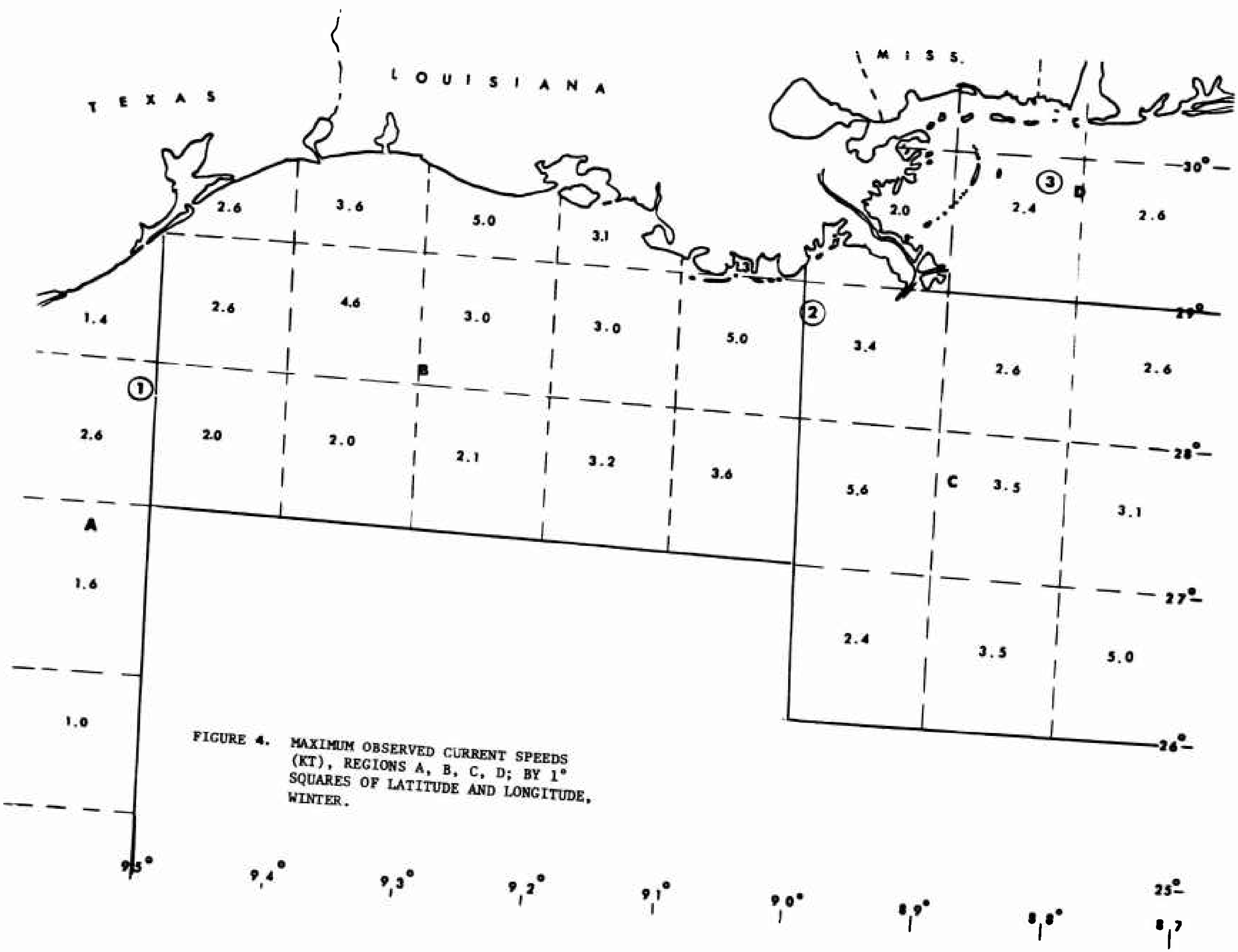


FIGURE 4. MAXIMUM OBSERVED CURRENT SPEEDS (KT), REGIONS A, B, C, D; BY 1° SQUARES OF LATITUDE AND LONGITUDE, WINTER.

Table 4
Monthly Current Data off Sabine and Galveston

Item[1]	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
I.					$\phi > 29°$, λ 93-94° Off Sabine							
Vel.	.82	.75	.73	.62	.78	.48	.39	.52	.64	.62	.68	.59
Dir.	W	W	W	W	WNW	W	WNW	WNW	W	WNW	WNW	WNW
No. 0	119	147	211	194	248	262	243	390	240	217	191	169
II.					$\phi > 29°$, λ 94-95° Off Galveston							
Vel.	.35	.38	.37	.44	.38	.27	.18	.30	.36	.41	.25	.35
Dir.	W	W	W	W	W	W	NNW	WNW	W	WSW	W	W
No. 0	113	127	159	169	181	177	152	179	156	139	157	114

[1]Item
I. Segment
Vel. Knots
Dir. Towards
No. 0 No. of observations

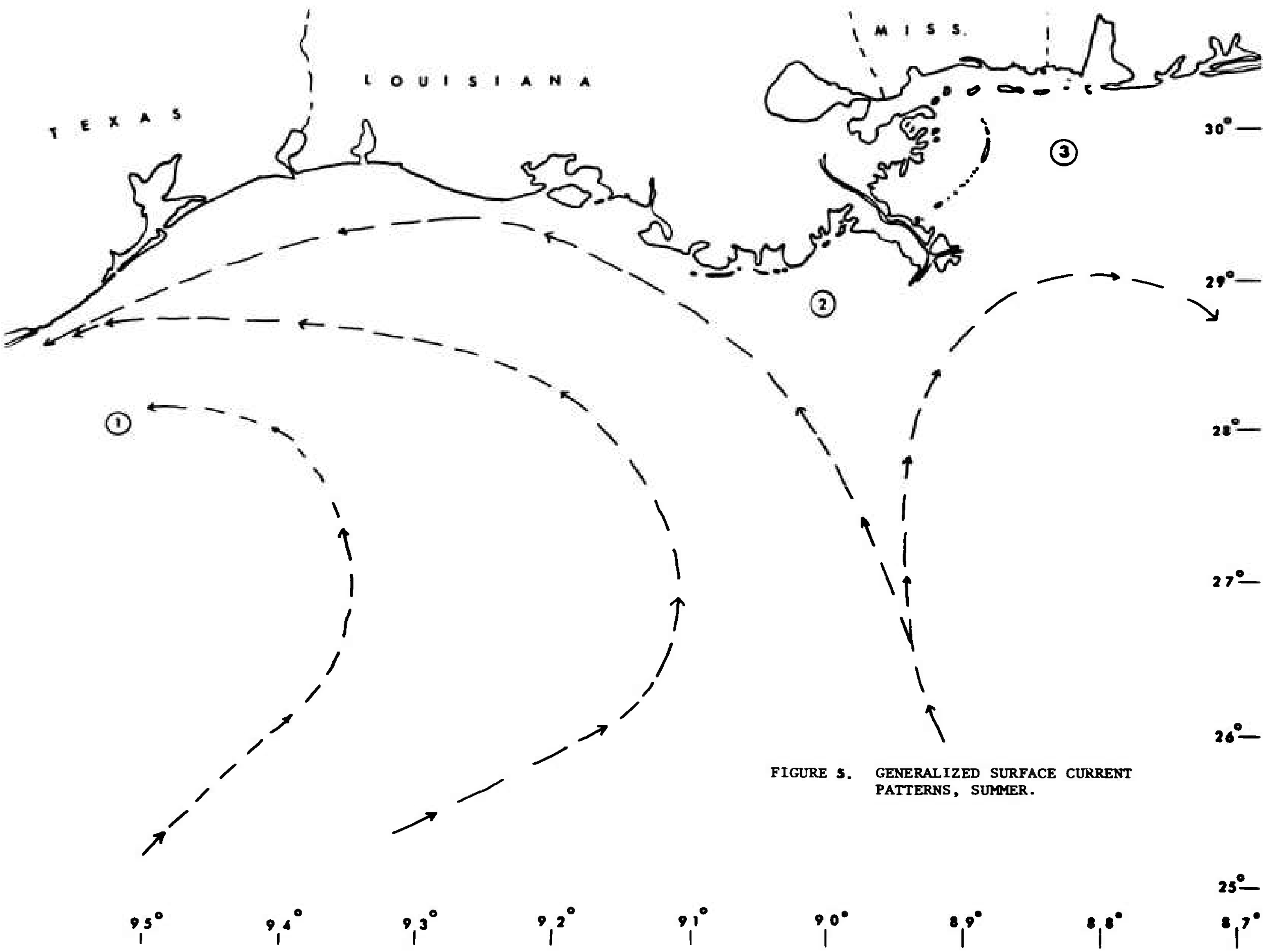


FIGURE 5. GENERALIZED SURFACE CURRENT PATTERNS, SUMMER.

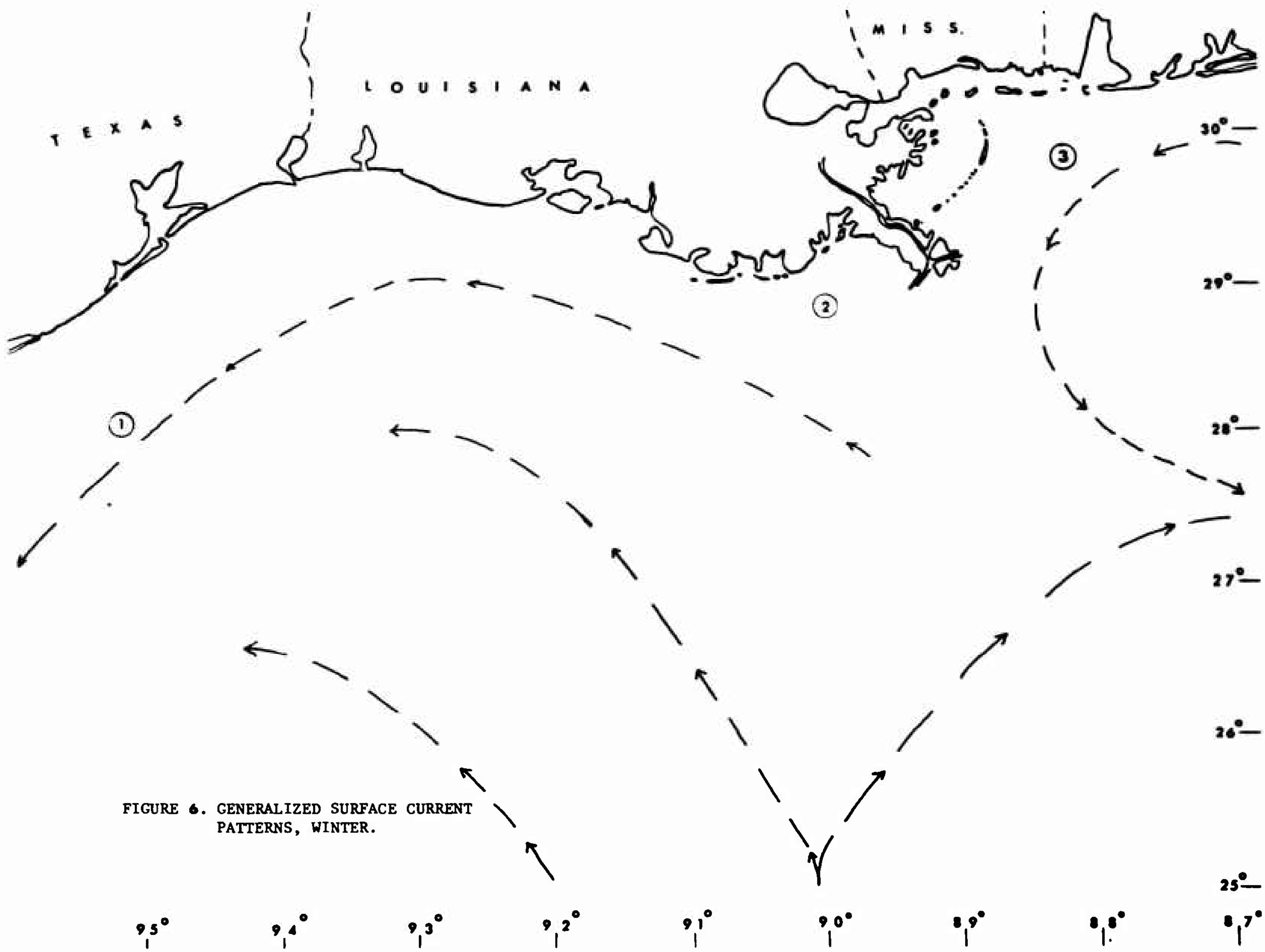


FIGURE 6. GENERALIZED SURFACE CURRENT PATTERNS, WINTER.

Deepwater Port Site 3 has a complicated current pattern. During the winter months Figure 6 shows the generalized flow to be toward the west or southwest. For summer conditions the generalized flow is shown to be towards the east (Figure 5). This reversal of flow appears to be due to the northward extension of the Gulf of Mexico loop current during summer months.

3.2 Wind

Section 2.0 indicated the importance of wind drift in determining the movement of an oil spill. All three Deepwater Port sites have a predominance of wind observations from the south-southwest during summer and winter seasons. The average directional wind velocities during the summer season for all three sites is between 8.0 and 11.0 knots. As expected, during the winter the average velocities are larger and of greater range averaging between 10.0 and 17.0 knots.

3.3 Drift Technique

The usual method used to predict the movement of an oil spill is to add the surface current vector and the wind vector. The resultant vector shows the movement of the center of an oil spill as it was affected by wind and surface currents. This technique works when the surface currents are generated by forces other than the wind field. If the wind field plays an important role in the generation of the current system then a simple addition of the current vector and wind vector will not give reliable projections of oil spill movement. Preliminary analysis of the data seemed to indicate that there was a correlation between the current system and wind system at each Deep Water Port Site.

It is of interest to examine the relationship between the wind direction and the current direction. Specifically, are they independent? We wish to test the null hypothesis that the current direction is independent of the wind direction. The data are the frequency of wind and current directions for eight points of the compass for the summer and winter periods. Because the data are frequencies, the chi-square test of independence was chosen to test the null hypothesis.

Summer and winter conditions for each Deep Water Port site were examined separately. That is, the direction of the summer wind versus the direction of the summer current was examined for each DWP site. The same procedure was repeated for winter conditions at each site.

Six different combinations were examined. The results are given in Table 5. In all six, the result is that the direction of the surface current is not independent of the wind direction.

The direction of the surface current is related to the direction of the wind.

Table 5
Chi-square Values for Test of Independence

DWP	Summer	Winter
1	975.05*	1452.99*
2	2819.86*	4570.36*
3	17.25*	69.09*

*Significant at the 0.05 α level

The correlation of the wind direction and current direction indicate that a simple vector addition of the surface current and wind drift will not suffice. The data does not allow a quantification of the effect of wind on the current regime. For this reason we will use two methods to drift the oil. First, it is assumed that the currents in the area are produced only by wind effects. The oil will be transported at 3.5% of the wind speeds given in Table 1. Second, using Tables 1 and 3, the method of vectorially adding the wind drift and surface current will be used. The actual projections of oil spill movement will be somewhere between these two extremes. The wind was presumed to stay within the same octant throughout the test periods.

The drifting mechanism used does not consider local effects such as long-shore drift or fresh water plumes from rivers, or extreme currents (Figures 3-4). These processes can change the total area coverage of a potential spill, as well as the potential impact site and time of impact. However, these are unquantified effects and are subject to further research.

4.0 PROJECTIONS OF OIL SPILL MOVEMENT

4.1 DWP 1

Oil spill projections for both summer and winter seasons are shown in Figures 7-12 and 13-18. Figures 7-12 are projections based solely on wind-driven currents at each DWP. Figures 13-18 are projections based on an addition of wind drift and current drift at each DWP.

A pure wind-drift current system develops similar oil spill projection patterns for both summer and winter conditions for DWP 1. The possibility exists that the entire coastline from the Corpus Christi area to west of Sabine Lake could be affected by an oil spill. Minimum travel time for a spill to impact the coastline is estimated to be 34 hours for summer and winter conditions. The wind data indicates that approximately 65% of the time a spill from DWP 1 would spread to the Texas coastline.

The technique of adding the wind drift to the current drift gives a very different picture from the pure wind drift case. The highest environmental risks both during the summer and winter seasons centers around a 50-mile stretch of beach in the area of Matagorda Bay. The minimum travel time is 27 hours for winter conditions and 31 hours for summer conditions versus 34 hours for the pure wind drift technique. The probability of impact has decreased slightly to 55-60% from the pure wind drift value of 65%.

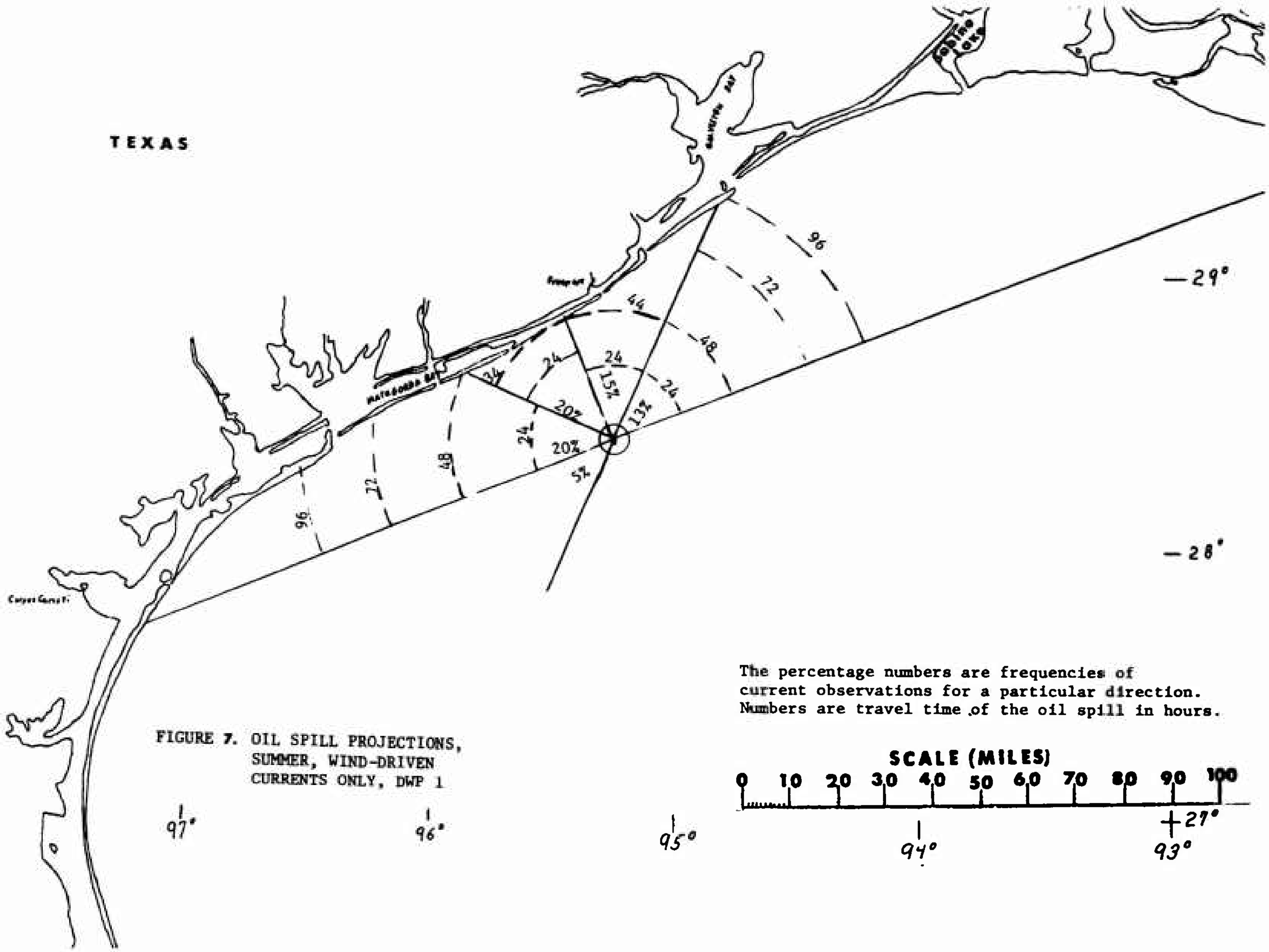


FIGURE 7. OIL SPILL PROJECTIONS, SUMMER, WIND-DRIVEN CURRENTS ONLY, DWP 1

The percentage numbers are frequencies of current observations for a particular direction. Numbers are travel time of the oil spill in hours.

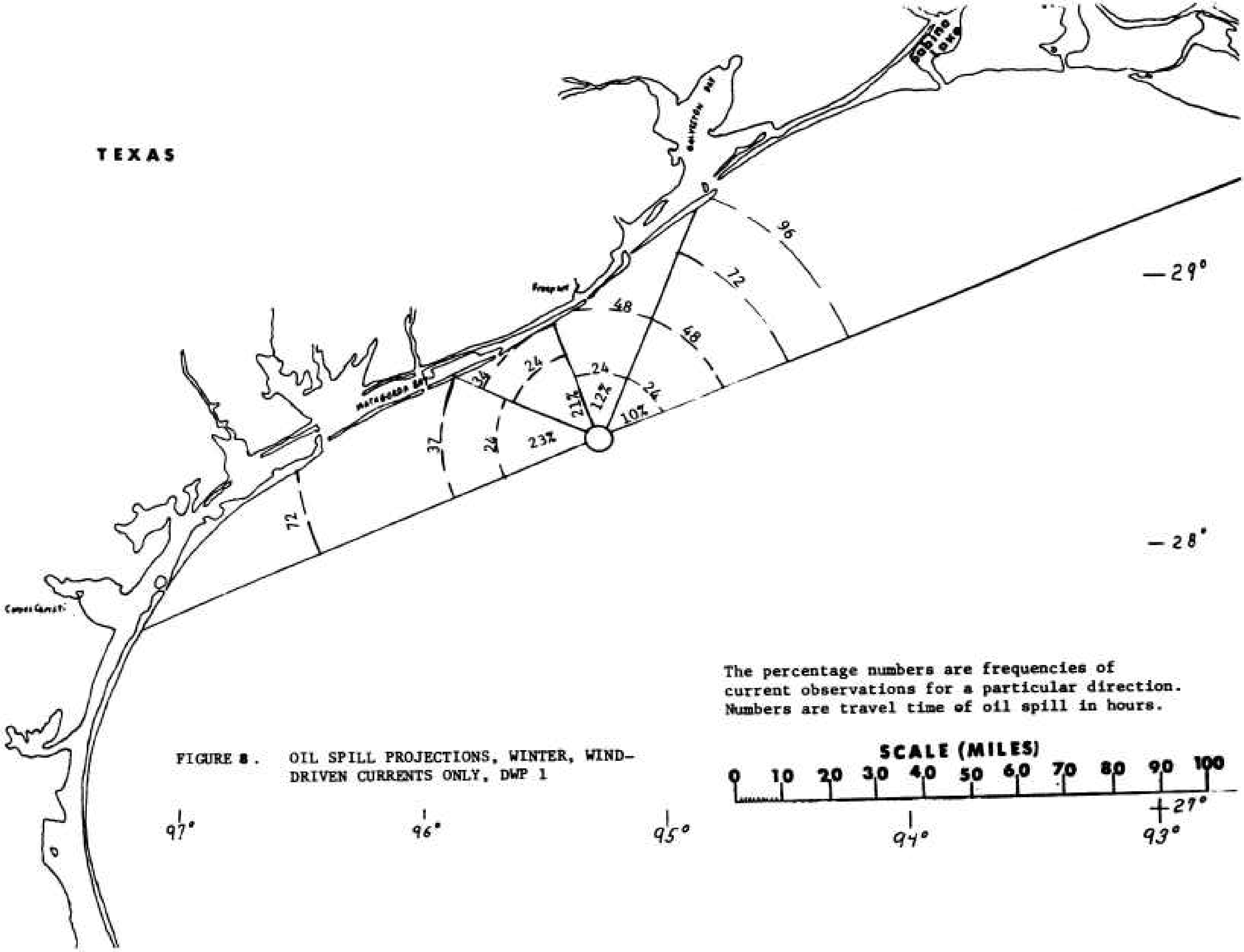
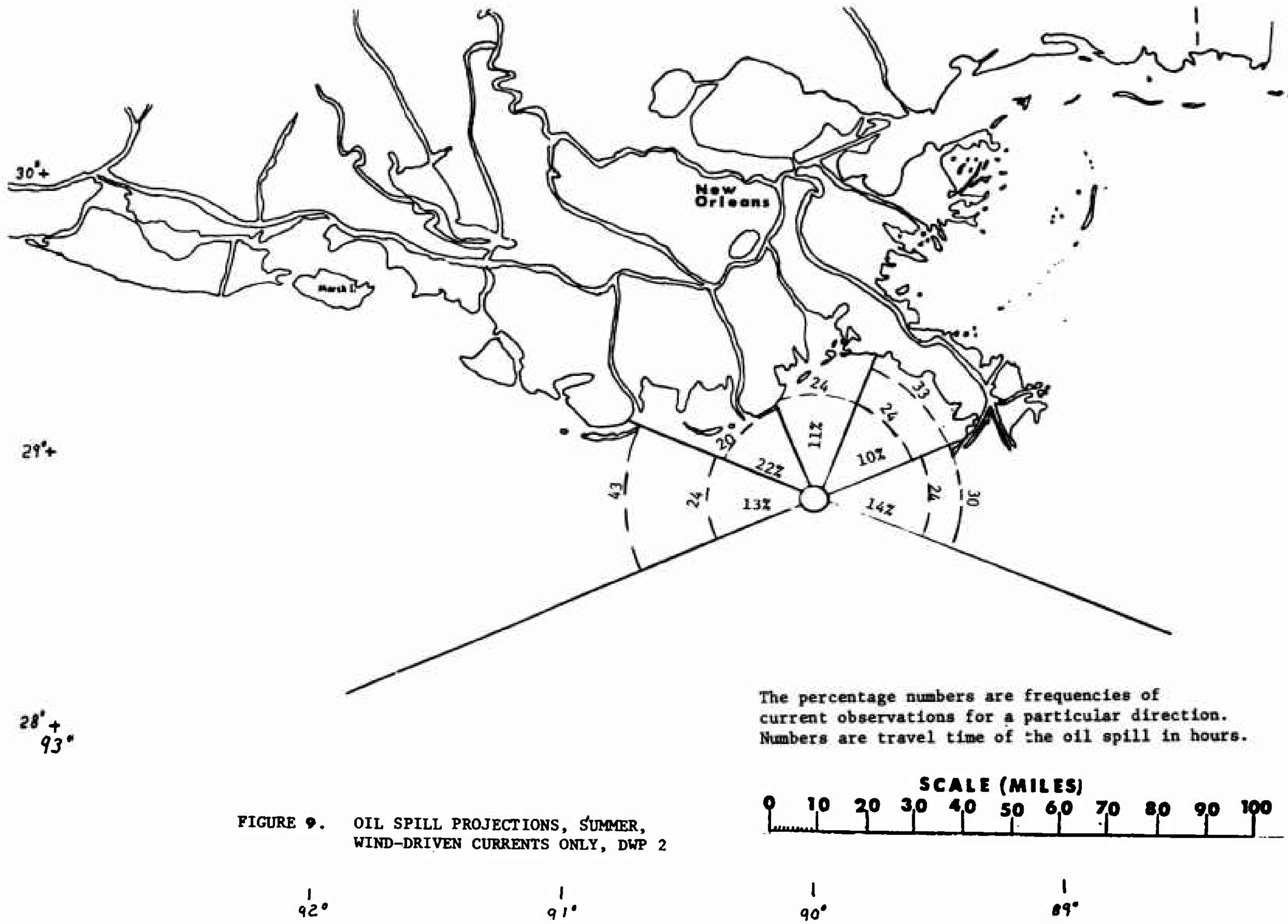


FIGURE 8. OIL SPILL PROJECTIONS, WINTER, WIND-DRIVEN CURRENTS ONLY, DWP 1

The percentage numbers are frequencies of current observations for a particular direction. Numbers are travel time of oil spill in hours.



The percentage numbers are frequencies of current observations for a particular direction. Numbers are travel time of the oil spill in hours.

FIGURE 9. OIL SPILL PROJECTIONS, SUMMER, WIND-DRIVEN CURRENTS ONLY, DWP 2

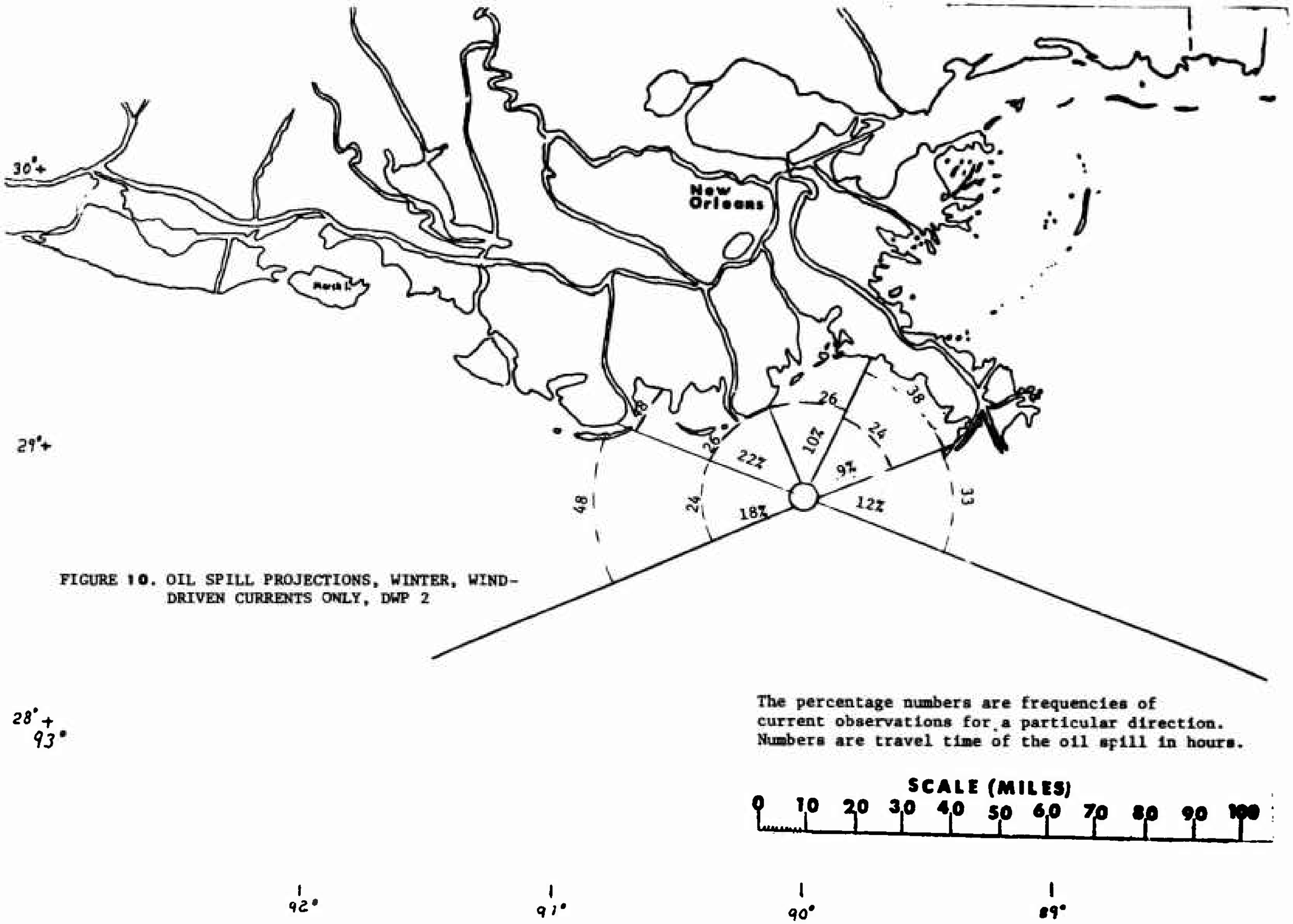
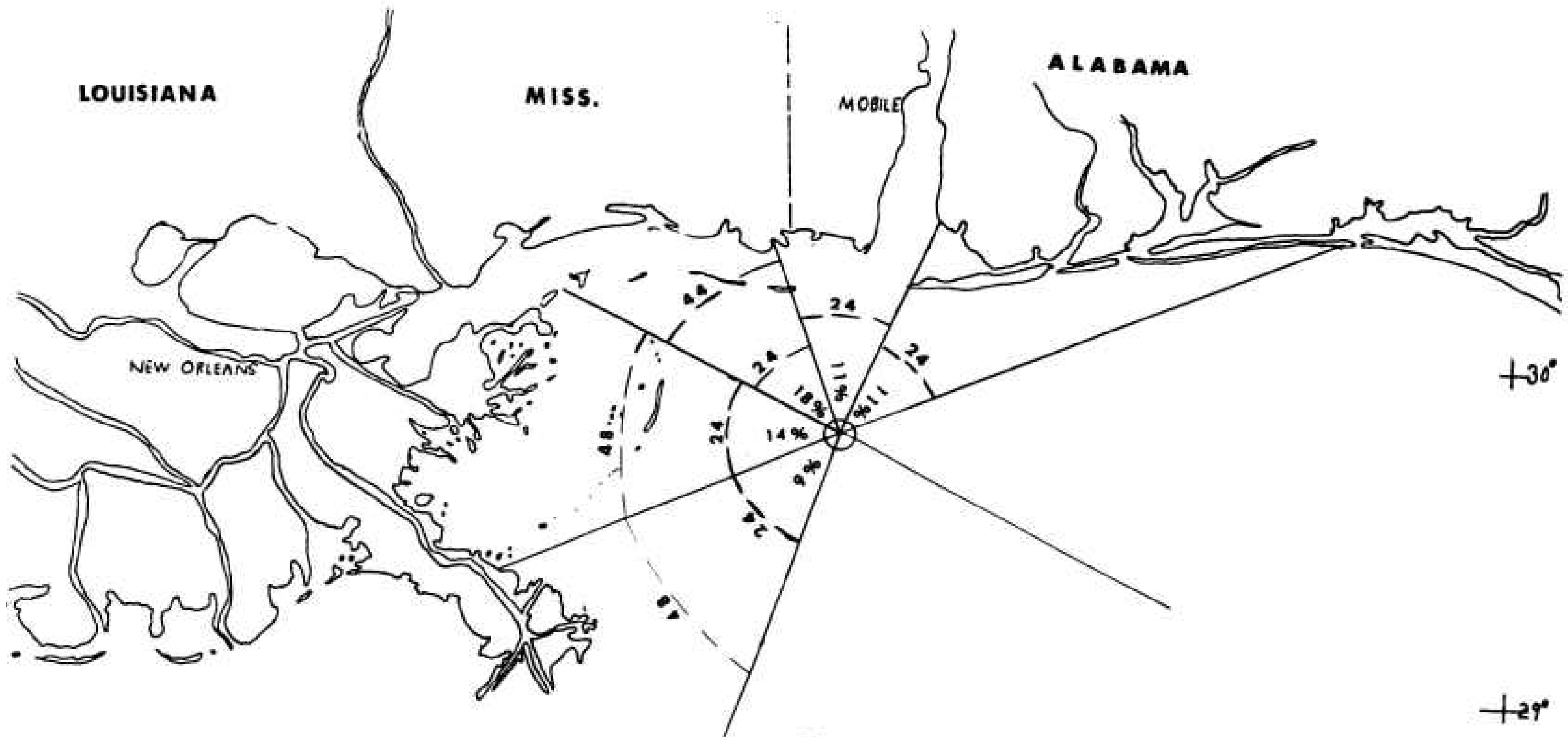


FIGURE 10. OIL SPILL PROJECTIONS, WINTER, WIND-DRIVEN CURRENTS ONLY, DWP 2

The percentage numbers are frequencies of current observations for a particular direction. Numbers are travel time of the oil spill in hours.



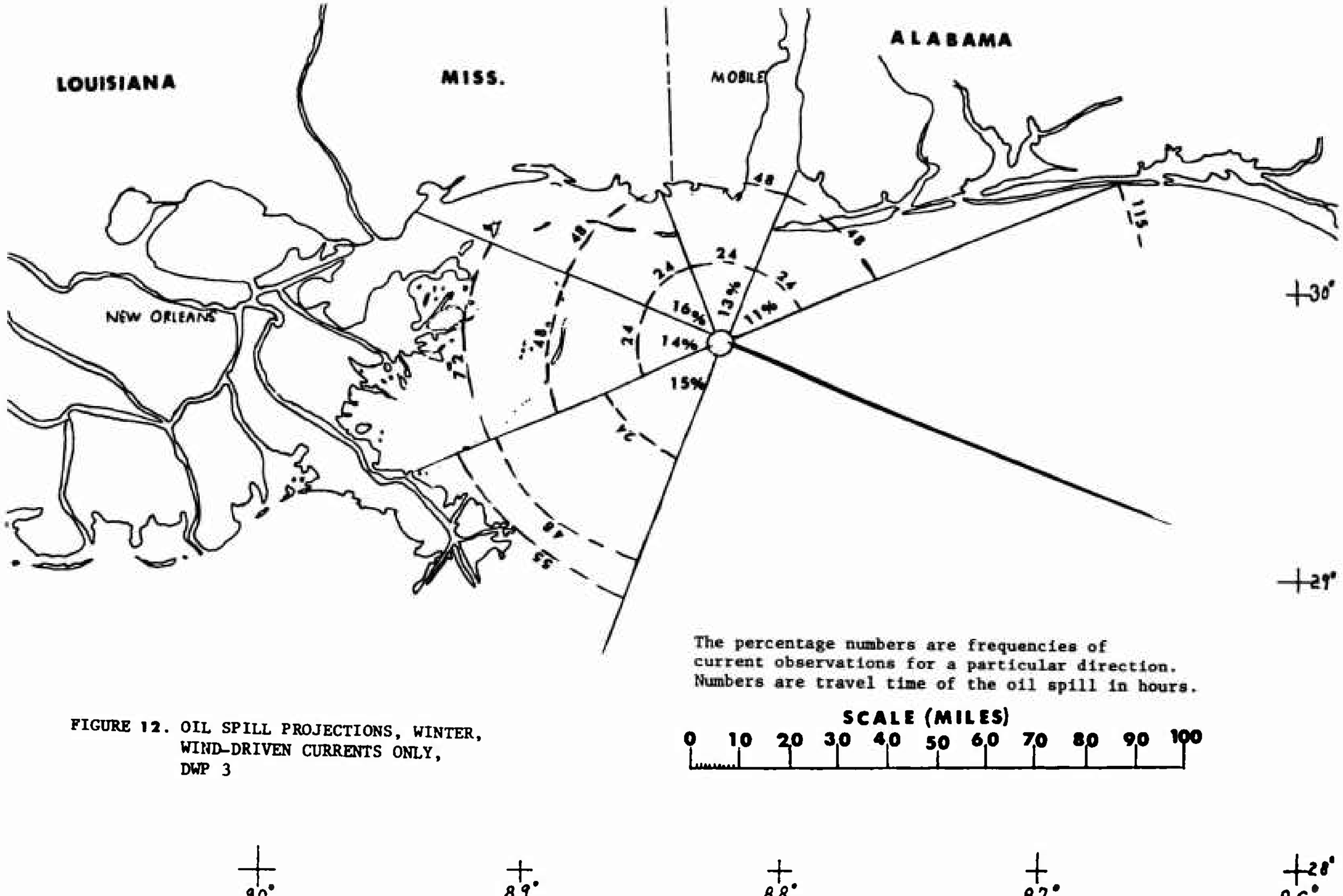
The percentage numbers are frequencies of current observations for a particular direction. Numbers are travel time of the oil spill in hours.

SCALE (MILES)

0 10 20 30 40 50 60 70 80 90 100

FIGURE 11. OIL SPILL PROJECTIONS, SUMMER, WIND-DRIVEN CURRENTS ONLY, DWP 3

90° 89° 88° 87° 86° 28°



The percentage numbers are frequencies of current observations for a particular direction. Numbers are travel time of the oil spill in hours.

FIGURE 12. OIL SPILL PROJECTIONS, WINTER, WIND-DRIVEN CURRENTS ONLY, DWP 3

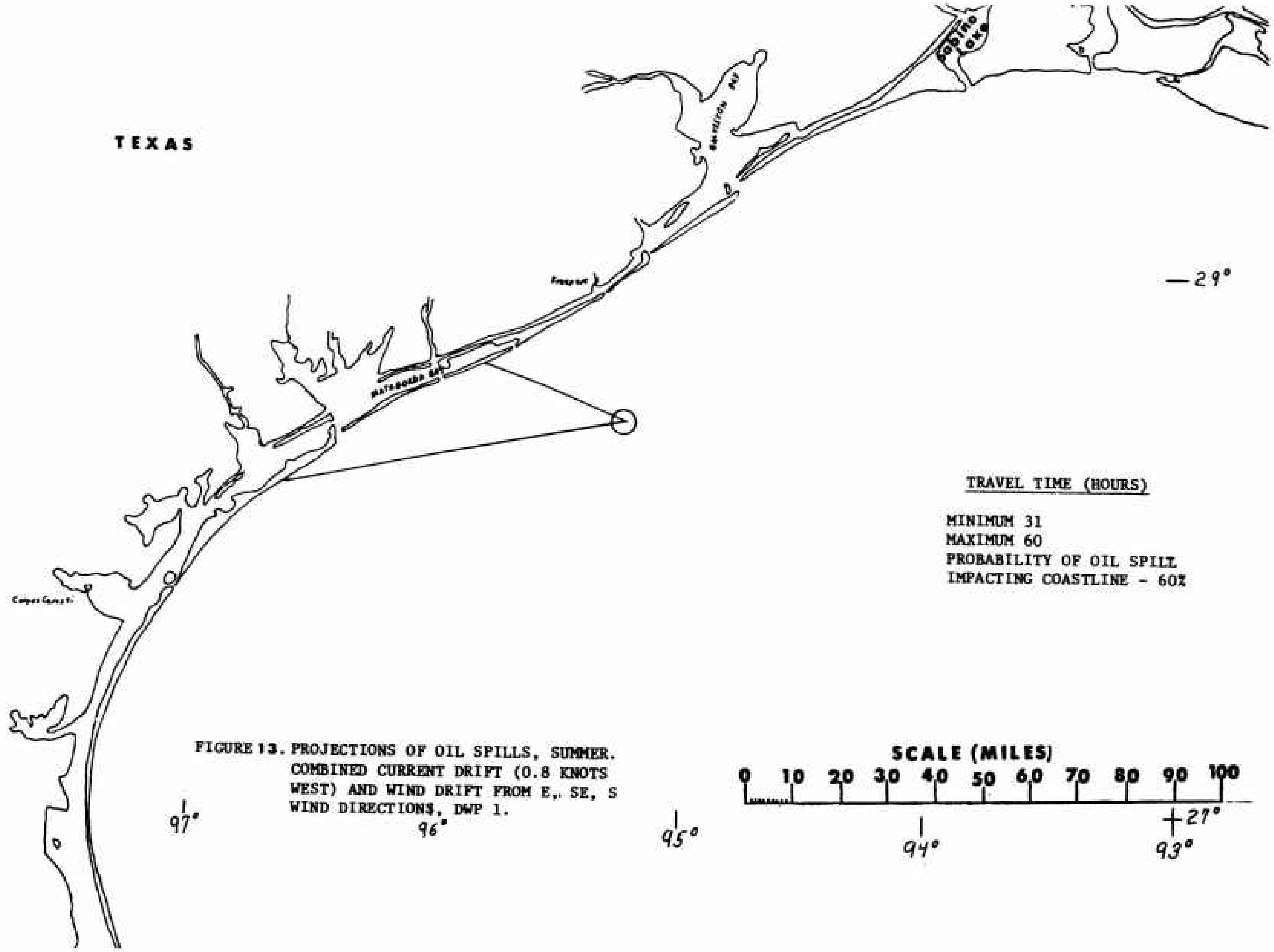


FIGURE 13. PROJECTIONS OF OIL SPILLS, SUMMER. COMBINED CURRENT DRIFT (0.8 KNOTS WEST) AND WIND DRIFT FROM E, SE, S WIND DIRECTIONS, DWP 1.

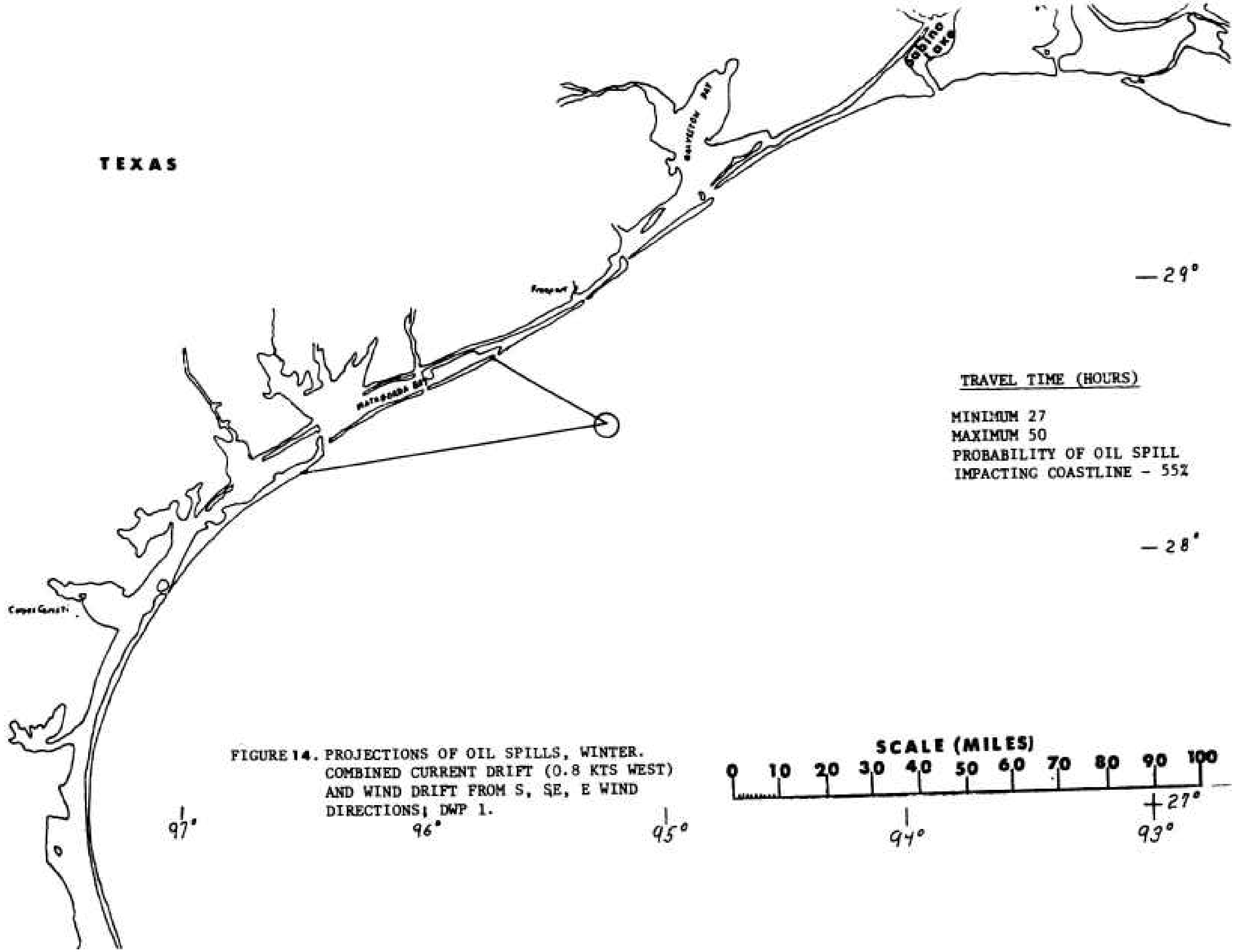
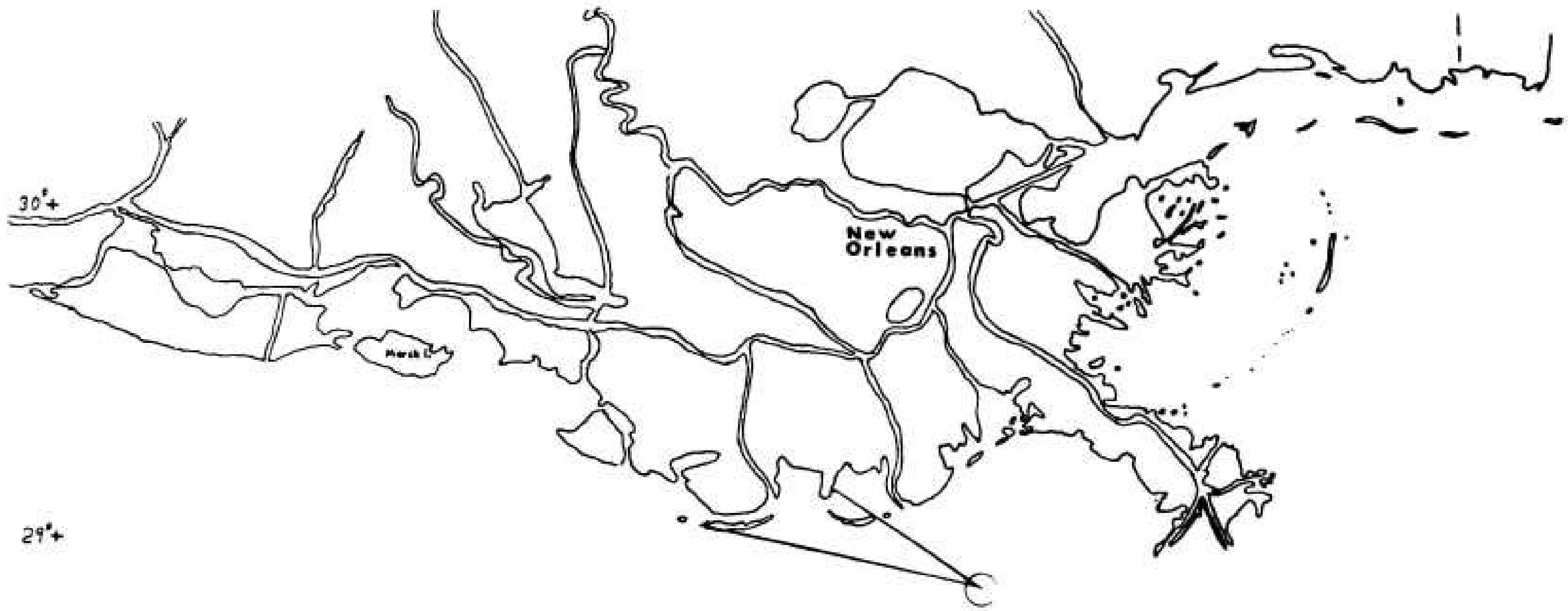


FIGURE 14. PROJECTIONS OF OIL SPILLS, WINTER. COMBINED CURRENT DRIFT (0.8 KTS WEST) AND WIND DRIFT FROM S, SE, E WIND DIRECTIONS; DWP 1.



TRAVEL TIME (HOURS)

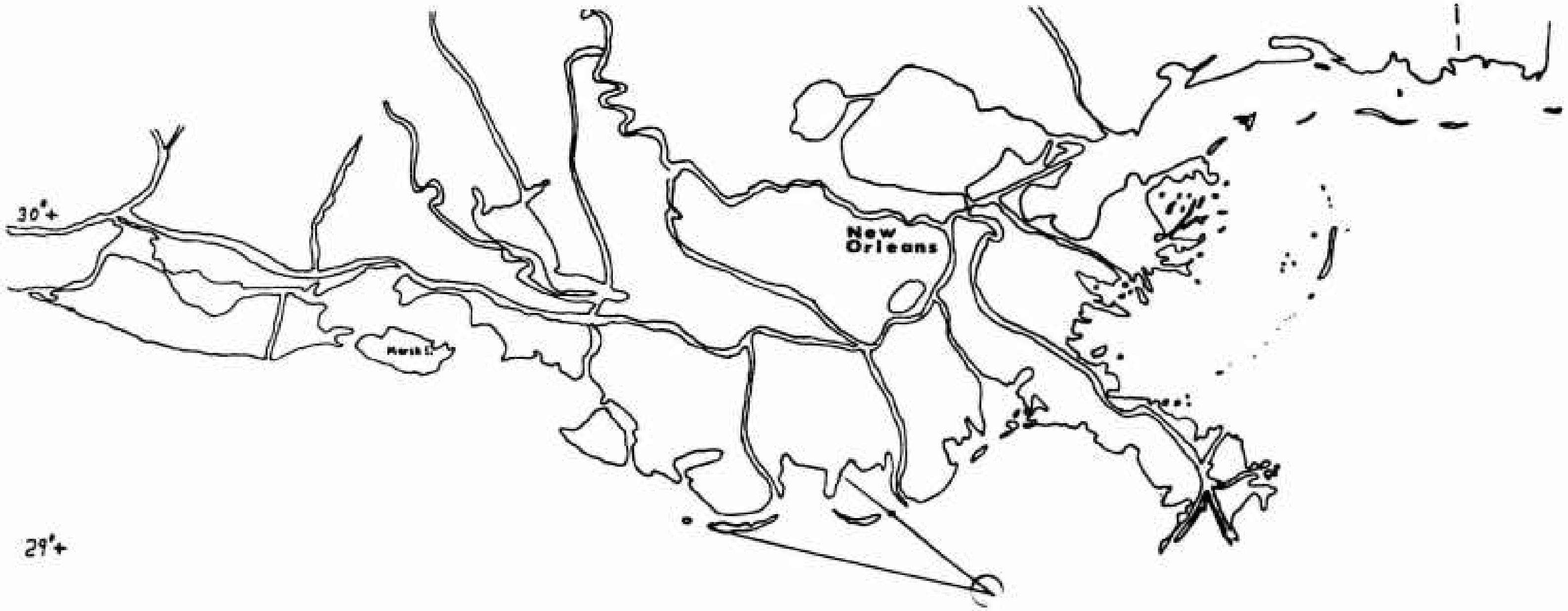
MINIMUM 33
MAXIMUM 66
PROBABILITY OF OIL SPILL IMPACTING COASTLINE - 40%

FIGURE 15. PROJECTION OF OIL SPILLS, SUMMER. COMBINED CURRENT DRIFT (0.8 KTS WEST) AND WIND DRIFT FROM S, SE, SW WIND DIRECTIONS, DWP 2.

28° + 93°

SCALE (MILES)
0 10 20 30 40 50 60 70 80 90 100

92° 91° 90° 89°



TRAVEL TIME (HOURS)

MINIMUM 19
MAXIMUM 66
PROBABILITY OF OIL SPILL
IMPACTING COASTLINE - 35%

FIGURE 16. PROJECTION OF OIL SPILLS, WINTER. COMBINED CURRENT DRIFT (0.8 KTS WEST) AND WIND DRIFT FROM S, SE, SW WIND DIRECTIONS, DWP 2.

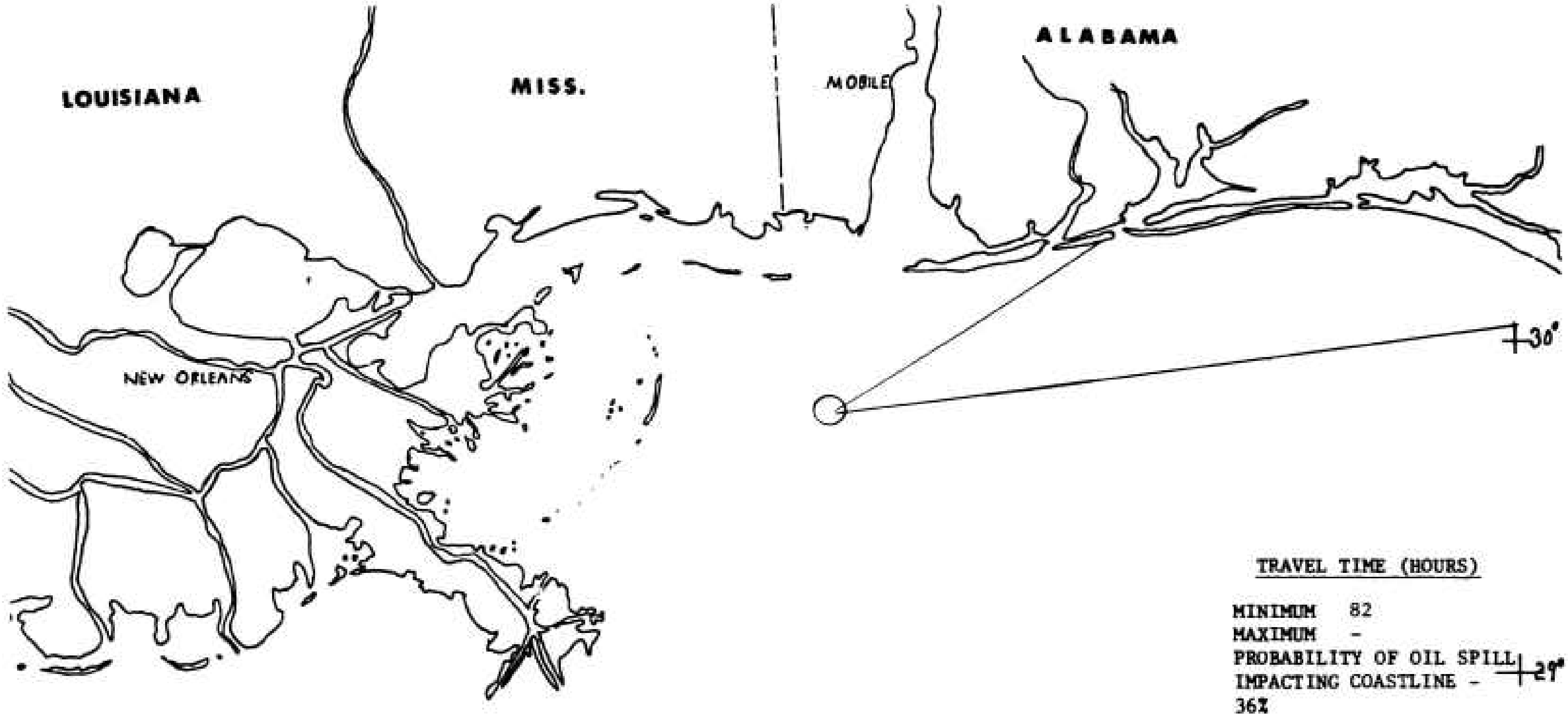


FIGURE 17. PROJECTIONS OF OIL SPILLS, SUMMER. COMBINED CURRENT DRIFT (0.6 KTS EAST) AND WIND DRIFT FROM SE, S, SW WIND DIRECTIONS, DWP 3.

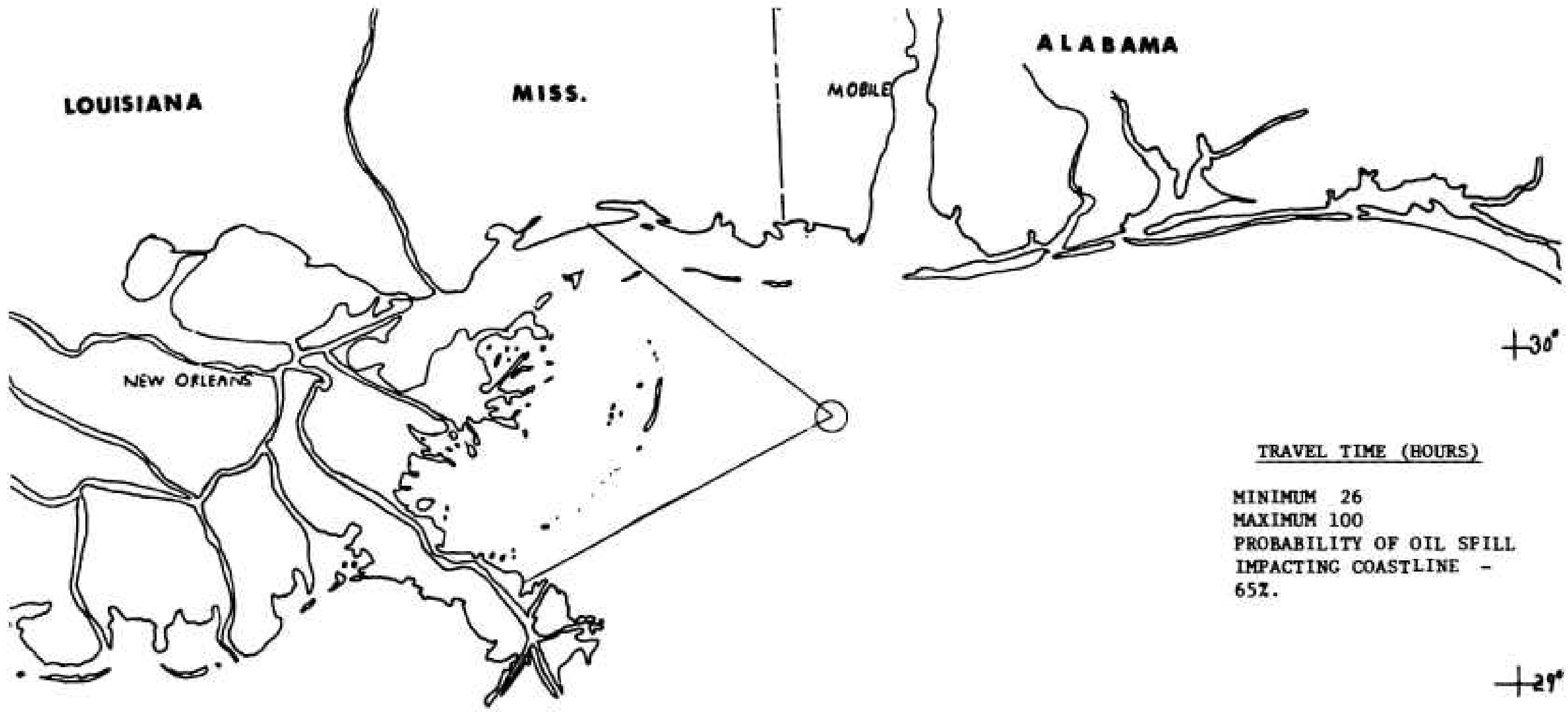
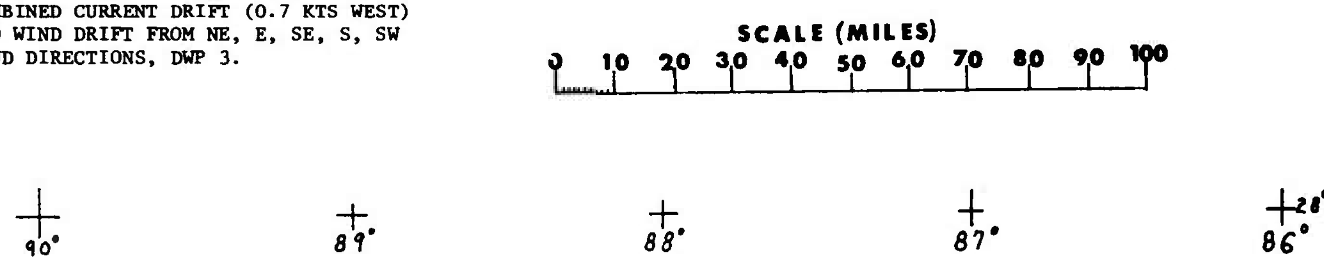


FIGURE 18. PROJECTIONS OF OIL SPILLS, WINTER. COMBINED CURRENT DRIFT (0.7 KTS WEST) AND WIND DRIFT FROM NE, E, SE, S, SW WIND DIRECTIONS, DWP 3.



4.2 DWP 2

The effects of an oil spill occurring at DWP 2 is illustrated in Figures 10, 11, 15 and 16. As was the case for DWP 1, a pure wind-driven system increases the area of coastline effected when compared to a combined current drift and wind drift.

The minimum travel time to impact the shoreline for summer conditions is 26 hours for a spill driven solely by the wind and 33 hours for a spill driven by currents and wind. For winter conditions the minimum times are 26 and 19 hours respectively.

The probability of a spill reaching the shoreline is 50% for the wind-driven current system and 35-40% for the combined current and wind drifts.

4.3 DWP 3

Figures 12 and 13 show oil spill projections for DWP 3, assuming a purely wind-driven spread of oil. Both summer and winter conditions indicate that extensive areas of the coastline could be impacted should a spill occur at DWP 3. Travel time to reach any part of the shoreline is approximately 36 hours for both summer and winter conditions.

The probability of impact is the same for either season, approximately 65%.

The projections of oil spill movement caused by a combined wind and current drift is given in Figures 17 and 18. For the summer season we combined an easterly current (based on the generalized summer current pattern) and the wind drift. This resulted in minimum impact time of 82 hours and an impact probability of 36%. For the winter season we combined a westerly current and the wind drift. This resulted in a minimum travel time of 26 hours and an impact probability of 65%.

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